UNIVERSITI PUTRA MALAYSIA

EFFICIENT SEQUENTIAL AND PARALLEL ROUTING ALGORITHMS IN OPTICAL MULTISTAGE INTERCONNECTION NETWORK

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

June 2005

بسم الله الرحمن الرحيم

" قُلْ إِنَّ صَلاتِي ونُسُكِي ومَحْيَايَ ومَمَاتِي
لِلَّهِ رَبِّ العَالَمِين "

سورة الأنعام آية(162)

Dedicated to my beloved family:

my parents; Abdullah and Neamah,
my wife, my kids; Abdurahman and Abdullah,
my brothers and my sister

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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June 2005

Chairman: **Associate Professor Mohamed Othman, PhD**

Faculty: **Computer Science and Information Technology**

As optical technology advances, there is a considerable interest in using this technology to implement interconnection networks and switches. Optical multistage interconnection network is popular in switching and communication applications. It has been used in telecommunication and parallel computing systems for many years. A major problem known as crosstalk is introduced by optical multistage interconnection network, which is caused by coupling two signals within a switching element. It is important to focus on an efficient solution to avoid crosstalk, which is routing traffic through an $N \times N$ optical network to avoid coupling two signals within each switching element.

Under the constraint of avoiding crosstalk, we are interested in realising a permutation that will use the minimum number of passes to send all messages. This routing problem is an NP-hard problem. Many algorithms are designed by many researchers to perform this routing such as window method, sequential algorithm, degree-descending algorithm, simulated annealing algorithm, genetic algorithm and ant colony algorithm.

This thesis explores two approaches, sequential and parallel approaches. The first approach is to develop an efficient sequential algorithm for the window method. Reduction of the execution time of the algorithm in sequential platform, led to a massive improvement of the algorithm speed. Also an improved simulated annealing is proposed to solve the routing problem. The efficient combination of simulated annealing algorithm with the best heuristic algorithms gave much better result in a very minimal time.

Parallelisation is another approach in our research. Three parallel strategies of the window method are developed in this research. The parallel window method with low communication overhead decreased 86% of the time compared to sequential window method. The parallel simulated annealing algorithm is also developed and it reduces 64% of the time compared to sequential simulated annealing.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenhi keperluan untuk ijazah Master Sains

ALGORITMA BERJUJUKAN DAN SELARI YANG BERKESAN RANGKAIAN SALING BERHUBUNG BERBILANG PARAS OPTIK

Oleh

MONIR ABDULLAH ABDUH KAID

Jun 2005

Pengerusi: **Profesor Madya Mohamed Othman, PhD**

Fakulti: **Sains Komputer Dan Teknologi Maklumat**

Dengan perkembangan teknologi optikal, terdapat minat yang menggalakkan dalam menggunakan teknologi ini untuk implementasi pelbagai hubungan rangkaian dan suis. Rangkaian saling Behubung berbilang paras optik adalah lebih terkenal dalam aplikasi suis dan komunikasi. Ia telah digunakan dalam sistem pengkomputeran telekomunikasi dan selari sejak bertahun lalu. Masalah utama yang dikenali sebagai 'crosstalk' telah diperkenalkan oleh rangkaian saling Behubung berbilang paras optik, yang mana ia disebabkan oleh dua isyarat berpasangan di dalam unsur suis. Adalah penting untuk mengfokuskan kepada penyelesaian yang efisyen untuk mengelakkan 'crosstalk', dengan trafik dihantar melalui rangkaian optikal $N \times N$ untuk mengelakkan dua isyrat berpasangan dalam setiap unsur suis.

Di bawah syarat dalam mengelakkan 'crosstalk', kami berminat dalam penggunaan pilihaturan yang menggurakan bilangan laluan paling minimum bagi menghantar semua mesej. Masalah penghantaran ini ialah masalah 'NP-hard'. Pelbagai algoritma telah dicipta oleh ramai penyelidik untuk membuat penghantaran seperti kaedah tingkap, algoritma

jujukan, algoritma penurunan darjah, algoritma simulasi 'annealing', algoritma genetik dan algoritma koloni semut.

Tesis ini mendalami dua pendekatan; jujukan dan selari. Pendekatan pertama, kami membangunkan algoritma jujukan yang efisyen untuk kaedah tingkap. Pengurangan masa pelaksanaan oleh algoritma jujukan tersebut membawa perubahan yang ketara kepada kelajuan algoritma tersebut. Kami juga mencadangkan simulasi 'annealing' yang telah diperbaiki ke atas masalah penghantaran. Kombinasi yang baik antara algoritma simulasi 'annealing' dengan algoritma jangkaan terbaik menghasilkan keputusan yang lebih baik dalam waktu yang singkat.

Keselarian adalah satu lagi pendekatan dalam penyelidikan kami. Tiga strategi algoritma selari dari kaedah tingkap telah dibangunkan dalam penyelidikan ini. Kaedah tingkap selari dengan beban komunikasi yang rendah menurun sebanyak 86% dari segi masa jika dibandingkon dengan kaedah tingkap jujukan. Kami turut membangunkan simulasi 'annealing' selari berkenaan masalah ini. Simulasi 'annealing' selari mengurangkan masa sebanyak 64% jika dibandingkan dengan simulasi 'annealing' jujukan.

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MONIR ABDULLAH ABDUH KAID

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LIST OF ABBREVIATIONS

COW	Cluster Of Workstations
GUI	Graphic Unit Interface
ISA	Improved Simulated Annealing
IWM	Improved Window Method
LOM	Lights Out Management
LB	Load Balancing
LBLO	Load Balancing with Low Communication Overhead
LUB	Load UnBalancing
MIMD	Multiple Instruction Multiple Data
MIN	Multistage Interconnection Network
NP	Non Polynomial
OMIN	Optical Multistage Interconnection Network
ON	Omega Network
OON	Optical Omega Network
PISA	Parallel Improved Simulated Annealing
PSA	Parallel Simulated Annealing
PVM	Parallel Virtual Machine
PIWM	Parallel Improved Window Method
SA	Simulated Annealing
SE	Switching Element
SSA	Sequential Simulated Annealing
SMP	Shared Memory Protocol
SPMD	Single Program Multiple Data
SWM	Sequential Window Method
WM	Window Method

CHAPTER 1

INTRODUCTION

1.1 Background

Communication among processors in a parallel computing system is always the main design issue when a parallel system is built or a parallel algorithm is designed. With advances in silicon technology, processor speed will soon reach the Gigahertz (GHz) range. Traditional metal based communication technology used in parallel computing systems is becoming a potential bottleneck. This requires either that significant progress needs to be made in the traditional interconnects, or that new interconnects technologies, such as optics, be introduced in parallel computing systems.

Multistage Interconnection Network (MIN) is very popular in switching and communication applications. It has been used in telecommunication and parallel computing systems for many years. This network consists of N inputs, N outputs, and S stages ($S = \log_2 N$). Each stage has $N/2$ Switching Elements (SEs), each SE has two inputs and two outputs connected in a certain pattern.

As optical technology advances, there is a considerable interest in using this technology to implement interconnection networks and switches. Fiber optic communications offer a combination of high speed, low error probability and gigabit translation capacity. When Optical MIN (OMIN) is used, there are common problems such as path loss, conversion of the signal at the switch and crosstalk.

The crosstalk problem is introduced by OMIN, which is caused by coupling two signals within a SE. To avoid the crosstalk problem, various approaches have been proposed by many researchers. In this research we are interested in a network called Omega Network (ON), which has the shuffle-exchange connection pattern. Since many other topologies are equivalent to omega topology, performance results obtained for ON are also applicable to other MINs (Wu and Feng, 1980). In the following, we will use ON and MIN interchangeably.

To transfer messages from a source address to a destination address in Optical ON (OON) without crosstalk, we need to divide the messages into several groups. Then, deliver the messages using one time slot (pass) for each group. In each group, the paths of the messages going through the network are crosstalk free. So, from the performance aspect, we want to separate the messages without any conflicts with other messages in the same group as well as to reduce the total number of the groups.

Many approaches have been proposed to avoid crosstalk in routing traffic through an $N \times N$ optical network by many researchers. Optical Window Method (WM) was proposed for finding conflicts among messages to be sent to the network to avoid crosstalk in OMIN (Shen *et al.*, 1999). When four heuristic algorithms sequential, sequential down, ascending degree and descending degree are used to simulate the performances in real time, the degree-descending algorithm gets the best performance (Miao, 2000). Genetic Algorithm (GA) is also used to improve the performance (Chunyan, 2001). The GA had much improvement in terms of average number of passes, but it was time consuming. Also, the Simulated Annealing (SA) algorithm is used to optimise the solution (Katangur *et al.*, 2002). Finally, the ant Colony (ACO) algorithm is proposed to optimise the solution (Katangur *et al.*, 2004a).

SA is an optimisation method used for combinatorial optimisation problems (Kirkpatrick, 1983). The SA method starts with a non-optimal initial configuration and works on improving it by selecting a new configuration and calculating the differential cost.

This thesis is planned to develop sequential and parallel algorithms for WM. Reduction of the execution time of the algorithm, in sequential and parallel platforms, led to a massive improvement of the algorithm speed. An Improved Simulated Annealing (ISA) is also proposed in this thesis. The efficient combination of SA algorithm with the best two heuristic algorithms, descending degree and sequential down will give much better results in a minimal time. The Parallel ISA (PISA) algorithm should improve the performance and reduce the time compared to the ISA.

1.2 Problem Statement

A major problem called crosstalk is introduced by OMIN which is caused by coupling two signals within a SE. When a crosstalk happens, a small fraction of the input signal power may be detected at another output although the main signal is injected at the right output. For this reason, when a signal passes many SEs, the input signal will be distorted at the output due to the loss and crosstalk introduced on the path.

To avoid crosstalk, time domain approach has been proposed, which is to route the traffic through an $N \times N$ optical network to avoid coupling two signals within each SE. The more efficient algorithm is the algorithm that generates less time slots (passes). Our goal is to design efficient routing algorithms to minimise the number of time slots (passes) for sending all the messages. That means the messages will be sent out in less time.

Our goal is to design efficient routing algorithms to reduce the execution time of WM that used to find the conflicts among messages. Also the SA approach still need to improve to minimize the number of time slots (passes) for sending all the messages. One way to speed up these routing algorithms is by implementing them in parallel platforms. Our investigations should provide a significant performance.